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| Comisión Panamericana de Normas Técnicas |
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| COPANT PROJECT 152-032 |
| DISTRIBUTION TRANSFORMERS ENERGY EFFICIENCY |

Proposal from Argentina- Rev 27.09.2022

**DISTRIBUTION TRANSFORMERS**

**Energy efficiency**

**1 Scope**

This COPANT standard is applied to define the energy efficiency level of liquid-immersed transformers covered by IEC 60076-1, with an apparent power up to 2500 kVA, a maximum equipment voltage (*U*m) up to 36 kV and an ONAN cooling system.

The energy efficiency levels given in Chapter 6 do not apply to the following transformers:

- transformers for high current rectifiers as described in IEC 61378 (all parts) and IEC 60146 (all parts);

- transformers for furnace applications;

- transformers for offshore applications, including transformers to be installed on fixed or floating offshore platforms, offshore wind turbines or on board ships and all types of vessels.

- transformers for emergency or temporary mobile installations; includes: transformers designed only to provide coverage for a specific time-limited situation when the normal power supply is interrupted due to an unplanned occurrence, such as a failure or station renovation, but not to permanently upgrade an existing substation.

- traction transformers;

- grounding transformers as described in 3.1.10 of IEC 60076-6:2007

- phase shifting transformers;

- measuring transformers (IEC 61869-1);

- transformers and autotransformers specifically designed for railway power systems;

- power transformers for traction catenaries for 16.67 Hz;

- transformers for high current rectifiers (IEC 61869-1);

NOTE 1 These are transformers specifically designed and intended to supply power to electronic loads or rectifiers, specified according to IEC 61378-1.

NOTE 2 This exclusion does not apply to transformers intended to deliver alternating current (ac) power from direct current (dc) sources, such as transformers for wind turbines and photovoltaic applications, as well as transformers designed for direct current (dc) transmission and distribution applications.

- transformers for railway power supply systems;

- underwater (submersible) transformers;

- starting, testing and welding transformers;

- starting transformers, specifically designed to start three-phase induction motors in order to eliminate voltage drops in the power supply;

NOTE 3 Examples are transformers that are deactivated during normal operation, used for the purpose of starting a rotating machine.

- transformers specifically designed for subway mining and explosion-proof applications;

- transformers that cannot meet energy efficiency requirements due to unavoidable size and weight limitations.

In this standard, the term "transformers" includes both separately wound transformers and autotransformers.

Transformers intended to deliver alternating current (ac) power from direct current (dc) sources, such as transformers for wind turbines and photovoltaic applications, as well as transformers designed for direct current (dc) transmission and distribution applications, are included in the scope of this standard.

**2 Normative references**

All normative documents mentioned below are indispensable for the application of this document.

When the list mentions normative documents in which the year of publication is indicated, it means that this edition must be applied. Otherwise, the current edition, including all amendments, must be applied.

IEC 60076-1, Power transformers - Part 1: General

**3 Terms and definitions**

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/

- ISO online navigation platform: available at [http://www.iso.org/obp.](http://www.iso.org/obp)

**3.1**

**efficiency**

Ratio between output active power and input active power.

NOTE: In this standard the transformer efficiency is based on apparent power, this is equivalent to assuming that the power factor is equal to one (see 4.1).

**3.2**

**total losses**

Active power consumed by the transformer at a given value of transmitted apparent power.

**3.3**

**efficiency index, method A**

**EIA**

Ratio of the transmitted apparent power of a transformer, minus total losses, to the transmitted apparent power of the transformer for a given load factor.

**3.4**

**peak efficiency index**

**PEI**

Higher value of the efficiency index of method A, which can be achieved with the optimal value of the load factor.

NOTE: To characterize the energy efficiency of transformers, it is useful to define an index that is relevant to transformer design and applicable to a wide range of uses, rather than a figure that varies second by second according to system conditions. For this reason, a metric, the peak efficiency index, has been developed and used that is based on active power losses and total transmitted apparent power and is independent of load phase angle, load factor and power rating.

**3.5**

**apparent input power,**

***Sentrada***

Product of input voltage and input current.

NOTE 1. In this standard the transformer efficiency is based on apparent power, this is equivalent to assuming that the power factor is equal to one (see 4.1).

NOTE 2. For three-phase transformers, multiply by √3.

**3.6**

**apparent power output**

***Ssalida***

Product between output voltage and output current.

NOTE 1. In this standard the transformer efficiency is based on apparent power, this is equivalent to assuming that the power factor is equal to one (see 4.1).

NOTE 2. For three-phase transformers, multiply by √3.

**3.7**

**transformer load factor**

***k***

ratio between the input current and the rated current of the transformer.

**3.8**

**load factor of peak efficiency index**

***k*PEI**

load factor for which the peak efficiency index is obtained (3.4).

**3.9**

**apparent transmitted power**

***kS*r**

product between the transformer load factor and the rated power.

**4 Calculation of efficiency and efficiency ratio**

**4.1 General**

Transformer efficiency is based on apparent power, this is equivalent to assuming that the power factor is equal to one. For transformers, efficiency is expressed as follows:

$Eficiencia= \frac{Sentrada-L}{Sentrada}=\frac{Ssalida}{Ssalida+L}$ (1)

The power *S* can be either the input apparent power or the output apparent power, resulting in two methods for calculating efficiency (method A and method B), both of which have been used historically.

**Method** A $Eficiencia= \frac{S-L}{S}$ (2)

 **Method** B $Eficiencia= \frac{S}{S+L}$ (3)

being:

*S* the apparent input or output power;

*L* the sum of no-load losses and losses due to load,

NOTE, *S* is defined as "apparent input power" in method A and as "apparent output power" in method B.

Due to the scope of this rule and in order to facilitate its understanding, it is conventionally assumed that:

- voltage and load current systems are symmetrical and sinusoidal;

- the line voltage is equal to the nominal voltage.

**4.2 Energy yield evaluation method.**

To consider energy efficiency in a practical manner, for the purposes of this standard, the power factor is assumed to be equal to one, and efficiency is defined based on an efficiency rating at a given load power.

**This standard adopts method A (according to TS IEC 60076-20:2017) to calculate the efficiency index.**

**4.3 Method A**

**4.3.1 General efficiency index formula (EIA )**

The efficiency index according to method A is calculated according to the formula (4) below, expressed in per unit:

 (4)

being:

 *P*0 the no-load losses measured at rated voltage, rated frequency and rated tap, expressed in watts (W);

*P*k the losses due to the load measured at rated current and rated frequency at the rated tap, corrected to the reference temperature, expressed in watts (W);

*S*r is the rated power of the transformer as defined in IEC 60076-1 expressed in volt-ampere (VA);

*k* the load factor.

This approach respects the philosophy of the IEC 60076 series transformer standards, which refers the power rating to the rated voltage and rated current of one of the transformer windings.

For the calculation it must be considered that the reference temperature at the nominal power chosen for the losses must be in accordance with IEC 60076-1.

**4.3.2 Peak efficiency index**

The peak efficiency index (PEI) is obtained when the no-load losses are equal to the losses due to the load and is obtained by substituting k in equation (4) with kPEI , indicated in the following formula:

 (5)

Therefore, the formula for calculating the PEI is given in equation (6):

 (6)

Losses are measured in accordance with the methods specified in the IEC 60076 series of transformers.

NOTE The value of equation (6) depends on the ratio Sr / √P K

**5 Specification of energy performance**

The energy efficiency of a transformer should be specified as follows:

* maximum losses due to load and maximum no-load losses;

No additional requirements can be added and one of the available energy performance levels must be selected.

**6 Energy efficiency levels**

**6.1 General**

This standard establishes two levels of energy efficiency

- level 1 is for basic energy performance;

- level 2 is for high energy yield.

For transformers having a power rating not included in these tables, the value of the losses should be linearly interpolated between the figures given for the nearest higher and lower power ratings:

**6.2 Liquid immersed transformers**

For all tables, a voltage-free regulation range of less than or equal to ± 5% is considered.

**Table 1 - Maximum losses due to load and maximum no-load losses for three-phase transformers with *U*m less than or equal to 14.5 kV, *S*r less than or equal to 2500 kVA and with rated frequency equal to 50 Hz.**

|  |  |  |
| --- | --- | --- |
| **Power rating**  | **Level 1** | **Level 2** |
| ***S*r** | ***P*o** | ***P*k** | ***P*o** | ***P*k** |
| **(kVA)** | **(W)** | **(W)** | **(W)** | **(W)** |
|  |  | 340 |  | 320 |
|  |  | 550 |  | 520 |
|  |  |  |  | 620 |
|  |  | 1050 | 145 | 1000 |
|  |  | 1650 | 215 | 1280 |
|  |  | 1750 |  | 1660 |
|  |  |  |  | 2370 |
|  |  | 3000 |  | 2850 |
|  |  | 3500 | 560 | 3320 |
|  | 850 | 4250 | 680 | 4040 |
|  | 1000 | 5000 | 800 | 4750 |
|  |  | 6000 | 960 | 5700 |
|  | 1450 | 7250 | 1160 | 6900 |
| 800 | 1750 | 8750 | 1400 | 8300 |
| 1000 | 2000 | 10500 |  | 10000 |
| 1250 | 2300 | 13800 | 1840 | 13100 |
| 1600 | 2700 | 17000 | 2160 | 16100 |
| 2000 | 3000 | 21500 | 2400 | 20400 |
|  | 3300 | 24800 | 2640 | 23600 |

**Table 2. Maximum losses due to load and maximum no-load losses for single-phase transformers with *U*m less than or equal to 14.5 kV, *S*r less than or equal to 100 kVA and with rated frequency equal to 50 Hz.**

|  |  |  |
| --- | --- | --- |
| **Power rating**  | **Level 1** | **Level 2** |
| ***S*r** | ***P*o** | ***P*k** | ***P*o** | ***P*k** |
| **(kVA)** | **(W)** | **(W)** | **(W)** | **(W)** |
| 5 |  |  |  |  |
|  | 45 |  |  |  |
|  |  |  |  |  |
|  |  | 600 |  | 570 |
|  | 110 | 900 | 90 | 850 |
| 63 | 220 | 1150 |  | 1100 |
|  |  |  | 215 |  |

**Table 3 - Maximum losses due to load and maximum no-load losses for three-phase transformers with *U*m greater than 14.5 kV and less than or equal to 36 kV, *S*r less than or equal to 2500 kVA and with rated frequency equal to 50 Hz.**

|  |  |  |
| --- | --- | --- |
| **Power rating**  | **Level 1** | **Level 2** |
| ***S*r** | ***P*o** | ***P*k** | ***P*o** | ***P*k** |
| **(kVA)** | **(W)** | **(W)** | **(W)** | **(W)** |
|  |  |  |  |  |
|  |  |  |  | 460 |
|  |  |  |  | 620 |
|  |  | 900 | 230 | 850 |
| 63 | 320 |  | 260 | 1420 |
|  | 420 | 1900 | 340 | 1800 |
|  | 600 | 2800 |  | 2650 |
|  |  | 3250 | 560 | 3100 |
|  | 850 |  | 680 | 3800 |
|  |  | 4800 | 760 | 4600 |
|  |  | 5600 | 960 | 5300 |
|  | 1250 | 6400 | 1000 | 6100 |
|  |  | 7600 |  | 7200 |
| 800 | 1800 | 9800 | 1400 | 9300 |
| 1000 | 2200 | 11700 | 1800 | 11100 |
| 1250 |  | 14200 | 2000 | 13500 |
| 1600 | 2900 | 17800 | 2300 | 16900 |
| 2000 | 3200 | 22000 | 2600 | 21000 |
|  | 3600 | 26000 | 2900 | 25000 |

**Table 4 - Maximum losses due to load and maximum no-load losses for single-phase transformers with *U*m greater than 14.5 kV and less than or equal to 36 kV, *S*r less than or equal to 25 kVA and with rated frequency equal to 50 Hz.**

|  |  |  |
| --- | --- | --- |
| **Power rating**  | **Level 1** | **Level 2** |
| ***S*r** | ***P*o** | ***P*k** | ***P*o** | ***P*k** |
| **(kVA)** | **(W)** | **(W)** | **(W)** | **(W)** |
|  |  | 320 |  |  |
|  |  | 440 |  | 420 |
|  | 110 | 660 | 90 |  |

**7 Tolerance**

**7.1 General**

The maximum losses in the tables do not include tolerances with respect to energy efficiency levels.

**7.2 Losses**

- The measured values of the losses due to the load referred to the reference temperature and the measured values of the no-load losses must not be greater than the corresponding value indicated in the tables.

- If the agreed value of any guaranteed loss is less than the corresponding value given in the table, then the tolerances stated in IEC 60076-1 may be used for the purpose of acceptance or rejection, provided that the corresponding value given in the tables is not exceeded.

**ANNEX A
(Regulatory)**

**National deviations applicable to Mexico**

Proposed transformer efficiency and loss tables at a frequency of 60 Hz.

Method B:

$$η= \frac{S}{S+L}$$

 Where:

 Ses the apparent power output.

 Les the sum of no-load losses and losses due to load.

For the determination of the efficiency, no-load losses and losses due to load referred to a load factor of 80 % derived from the measurement of losses at 100 % load and corrected to 85 °C and a unity power factor according to the following equation must be considered:

$$η= \frac{100 × (P × kVA × 1 000)}{\left( P × kVA × 1 000\right) + NL + (LL × P^{2} × T)}$$

 Where:

 Pes the unit load (0.8).

 kVAis the rated capacity in kVA.

 NLson the no-load losses at room temperature in W.

 LLson the losses due to the load at the reference temperature (85 °C) W.

 Tes the correction factor for pressure drop at 70 °C (0.953 332)

 **NOTE:** The rated capacity (volt ampere) must be a function of the voltage, frequency and rated electrical current values used for the calculation of losses and considering a unity power factor.

**Table 1 - Minimum efficiencies referred to a load factor of 80% for distribution transformers at a frequency of 60 Hz.**

|  |  |  |
| --- | --- | --- |
| **Type of power supply** | **Capacity in kVA** | **Basic insulation level**  |
| **Up to 95****(Class 15 kV)** | **Up to 150****(Class 18 kV and 25 kV)** | **Up to 200****(Class 34.5 kV)** |
| M o n o f f a s s i c |  | 98,61 % | 98,49 % | 98,28 % |
|  | 98,75 % | 98,63 % | 98,43 % |
|  | 98.90 % | 98,79 % | 98.63 % |
| 37,5 | 98,99 % | 98,90 % | 98,75 % |
|  | 99,08 % | 98,99 % | 98,86 % |
|  | 99,21 % | 99,12 % | 99,00 % |
|  | 99,26 % | 99,16 % | 99,06 % |
|  | 99,30 % | 99,21 % | 99,13 % |
| T r i f a s i c |  | 98,32 % | 98,18 % | 98,03 % |
|  | 98,62 % | 98,50 % | 98,35 % |
| 45 | 98,72 % | 98,60 % | 98,48 % |
|  | 98,86 % | 98,75 % | 98,64 % |
| 112,5 | 98,95 % | 98,85 % | 98,76 % |
|  | 99,03 % | 98,94 % | 98,86 % |
| 225 | 99,06 % | 98,96 % | 98,87 % |
|  | 99,11 % | 99,02 % | 98,92 % |
|  | 99,20 % | 99,11 % | 99,03 % |

 **NOTE:** Distribution transformers with capacities intermediate to those listed in this table must comply with the efficiencies of the next higher capacity.

**Table 2 - Total losses in W, referred to a load factor of 80 % at a frequency of 60 Hz.**

|  |  |  |
| --- | --- | --- |
| **Type of power supply** | **Capacity in kVA**  | **Basic impulse insulation level (kV)** |
| **Up to 95****totals** | **Up to 150****Totals** | **Up to 200****Totals** |
| M o n o f f a s s i c |  |  |  |  |
|  |  |  | 191 |
|  |  | 245 | 278 |
| 37,5 | 306 | 334 |  |
|  | 371 | 408 | 461 |
|  | 478 | 533 | 606 |
|  | 596 | 678 | 759 |
|  | 942 | 1 064 | 1 173 |
| T r i f a s i c |  | 205 |  | 241 |
|  | 336 | 365 | 403 |
| 45 | 467 | 511 | 556 |
|  | 692 | 759 | 827 |
| 112,5 | 955 | 1 047 | 1 130 |
|  | 1 175 | 1 286 | 1 384 |
| 225 | 1 708 | 1 892 | 2 057 |
|  | 2 155 | 2 375 | 2 620 |
|  | 3 226 | 3 592 | 3 918 |

 **NOTE 1:** These losses are maximum and no tolerance is allowed.

 **NOTE 2:** Total losses include load losses at 80% of rated capacity.

 **NOTE 3:** Distribution transformers with capacities intermediate to those in this table must comply with the losses for the preferably next higher capacity.

 **NOTE 4:** Losses caused by protection accessories are independent of transformer losses, so they are not considered for the calculation of transformer efficiency.